IMPLEMENTING THE AUTOMATED FEATURES OF THE PBFA-I CONTROL/MONITOR SYSTEM*

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Abstract

A control system is being provided for PBFA-I, an operational accelerator, to control subsystem functions such as sequencing of oil, water, gas, and vacuum controls, to coordinate charging and firing sequences, and to control safe and idle modes of the machine. Important design concepts in automating this system are: reliability, flexibility, and operability.

Reliability is a primary criterion for executing single pulsed power and physics experiments as well as for supporting extended experimental series without a failure that would cause downtime. Flexibility to respond to changes in operating parameters and experimenter needs is being implemented in two major areas: a modular I/O system to provide hardware flexibility, and structured software to ease software maintenance. Operability is increased with user-friendly software, and automatic sequencing.

Introduction

The Particle Beam Fusion Accelerator I (PBFA I) is a 30-terawatt machine with 36 modules that has been in operation for almost 5 years. It is housed in a facility with two small accelerators that share data acquisition and some process control systems. The control/monitor (C/M) system is responsible for the facility oil and water systems (the oil system has over 200,000 gallons of transformer oil and the water system has over 160,000 gallons of deionized water). C/M is also responsible for the two PBFA I insulating gas systems (SF6 and synthetic air), hydraulic transfer switches, charging system, and timing and firing systems.

In the 5 years of operation as a driver for fusion experiments, the criteria for an acceptable control system has changed considerably. As an example, PBFA I was brought on-line in a completely manual mode. Semi-automatic and automatic control modes were added later. In comparison, PBFA II, a 100-terawatt successor to PBFA I currently under construction cannot be operated without computer control. At the time of its construction, PBFA I was the largest accelerator Sandia had built or operated. What we have learned about operating and controlling such a large accelerator has been incorporated into the design of the PBFA II control system.

Baseline Status

The original proposal for automating the PBFA I C/M system called for automatic staging of the accelerator commencing 10-12 hours before the shot. However, the original system was too dependent on knowing how long each step in the preparation sequence would take. The preparation sequence timing for this R&D facility was never predictable and the sequence changed often. So a more flexible system was required; one that was not dependent on a set sequence of events and, yet, easy to operate.

Hardware And Software Baseline

Two years ago the C/M system was a manual control system (push-buttons and relays) that worked; it required a minimum of two operators, preferably three, and a shot-coordinator sequence operations. Custom-built, 8080-based

subsystem controllers were available and the programs for them were in various stages of completion. All controllers were communicating with the host computer (an HP-1000) and monitoring the various sensors. But only one, the SF6 gas controller, was partially running in semiautomatic mode, and that operation soon ended when the parameters were changed. There were many programs in the host computer to support the automatic control, but they were so closely tied to the system configuration and operating parameters that only the monitoring programs were usable. Figure 1 shows the hardware configuration, the dashed lines separate where control of the system resided in the manual, semiautomatic and automatic modes.
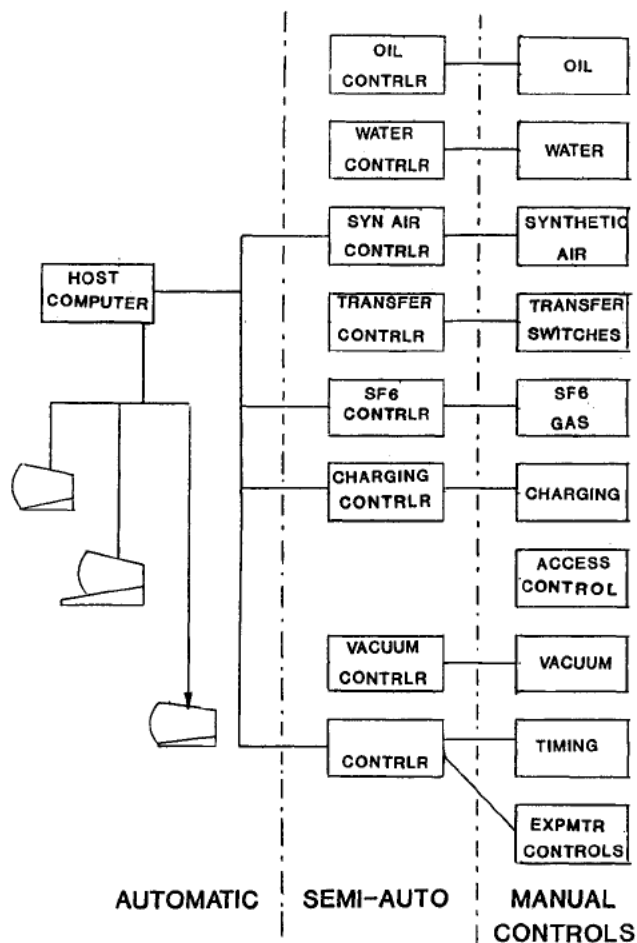

Figure 1. Hardware Configuration

The computer and the 8080 controllers supported the manual mode with monitoring, but if a controller or the computer were not available for the shot, manual control was used. The manual mode capability has remained in place as a backup while the automatic and semiautomatic capabilities were added. Figure 2 shows a simplified software configuration. The Monitor, Charging Graphics, Operator Interface, and Record Programs are real-time and active during the charging and firing sequence. The other programs and Update and Report Generator are run whenever convenient.

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14. ABSTRACT
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CAMAC modularized unit was written and reviewed. Another
proposal was to replace the subsystem controllers with a
Hewlett-Packard programmable controller. At this time,
neither proposal has been initiated due to funding
availability. The CAMAC system offers a major advantage in
that, being modular, it may be bought and implemented
piecemeal as funds become available or the needs become
greater.

To bring flexibility into the software and make the
functions performed by the 8080 controllers less hardware
dependent, decision-making functions were moved up into the
host computer for automatic mode operation. The 8080
controllers are reduced to I/O processors for the host and
perform simple I/O operations or short preprogrammed
sequences.

The controllers still retain the capability to perform
in-semiautomatic mode without the host computer. If the
8080 controllers are replaced, the I/O processing function
would be the most hardware independent and have the least
impact on the automatic system software.

Design & Implementation

After establishing criteria and a preliminary design
for an automatic control system, we proceeded with both the
human factors redesign of the control room and the
programming of the the 8080 controllers for the semi-
automatic mode. We started with the fluid transfer
systems, bringing these into semiautomatic mode after
considerable testing. The time required to complete this
activity can be broken down into three parts: learning the
existing software, writing new or revising old software,
and testing-debugging. The learning took approximately 30%
of the cycle; writing, 20%; and testing 50%. Once on-line,
these controllers freed one operator on the C/M team from
the time consuming job of monitoring the fluid transfer
control panels.

Problems & Solutions

In the process of bringing the fluid transfer
controllers up to semiautomatic mode, we found problems in
documentation that resulted from changes made in the system
without updating the drawings and schematics. We have now
established a set of as-built drawings that are up-to-date
and have supplemented them with notes and comments.

We also found design errors in the original hardware
in sections that had not been tested until the controllers
were in semiautomatic mode. We found during this program
testing phase that a "debugger," whether a program or
hardware, was an invaluable tool. With it, we could trace
I/O signals from the bus decoder out to the field wiring.
Also, we could single-step through a program checking
memory locations as often as we wished. The debugger we
used saved many hours of testing, changing code,
recompiling, and loading.

Human Factors Implementation

Each of the other subsystem controllers were
sequentially programmed and tested. When controllers were
running in semiautomatic, the human factors redesign was
completed with the installation of a new console designed
to be used by a single operator. The human factors
designed console put radio and P.A. system access at the
operator's fingertips for easy communications. The
critical manual controls were paralleled to the console.
Information readouts on the 8080 controllers were moved in
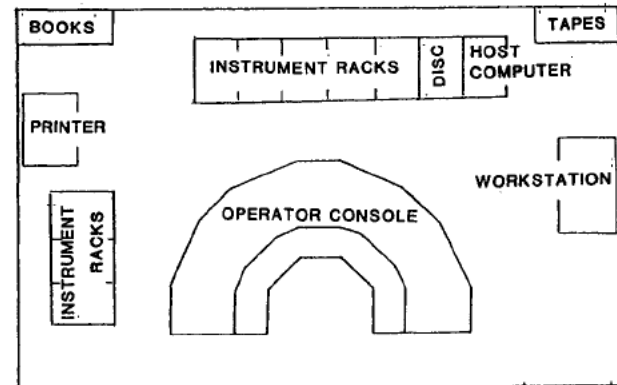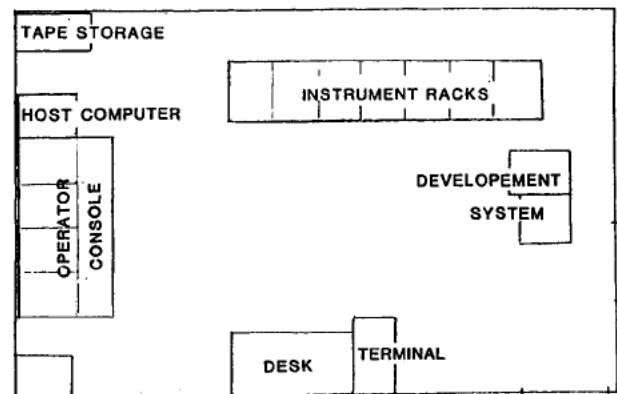the racks so they could be viewed from the console.

Figure 3. Control/Monitor Room Human Factors Redesign.

Host System Modification

The monitoring programs running on the host computer
were wasteful of resources and required considerable
operator attention. These were modified to query the
system memory for the needed parameters instead of asking
the operator. The disc file space usage was reduced to 1/7
of the former usage by dropping the transfer and storage of
large blocks of empty memory. Then CPU usage was reduced
so that other control programs could run concurrently. The
host system was upgraded to use FORTRAN '77 (a language
better suited to interactive use that FORTRAN '66), and the
system memory was expanded to allow the multi-program use
that would be required with the automated system. Figure 2
is a simplified software block diagram at this phase. The
real-time programs are active during the shot charging and
firing, while the others operate after the shot, whenever
convenient. During this period we also gained experience
operating the machine in a semiautomatic mode.

By this time, we had found that some of the procedures
programmed into the semiautomatic mode were overly
conservative, causing shots to be aborted when the problem
was not severe, and some programs had subtle "bugs" not
severe enough to cause damage but noticeable and sometimes
annoying.

Software Design

The design for the "Triggering and Firing (T&F)
Program" was finalized using this experience. The 8080
controllers needed to be reprogrammed (their programs were
in EPROM) to be only I/O processors when in the automatic
mode; their commands to begin short set sequences or single
actions would be sent from a "CONTROL" program (see Figure
4). The Monitor program will continue to do the same thing
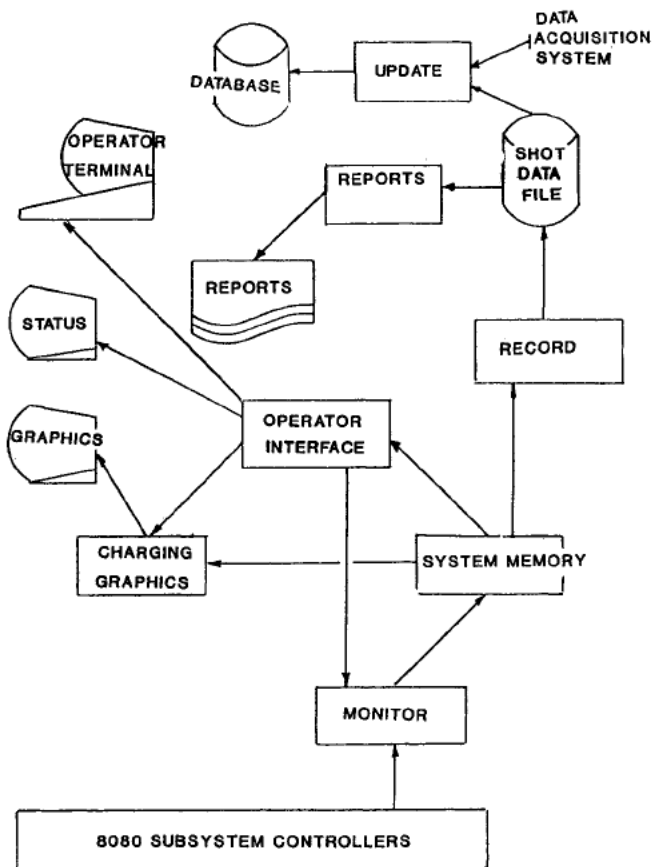that it had always done; instead of controlling its own

Figure 2. Original Software Configuration

Operability Baseline

The operation of the system in manual mode required considerable time and training and was still prone to errors, due to the large number of tasks the operator must perform. Not only must there be an operator in the control room, but fluid transfer controls had to be monitored in another part of the building. The two minutes immediately before the shot while the capacitor banks were charging were particularly stressful to the operators, and many mistakes occurred during this time. While operating in manual mode, changes in operating procedures from different experimenter needs, and changes to the accelerator hardware made the task of providing design criteria for a control system increasingly difficult.

Design Criteria

A C/M design team, comprised of the C/M coordinator, the shot coordinators, the facility supervisors, and the technical supervisor started the design of an automated system by defining the general criteria and answering the following questions: what do we want the operations to be like; how many operators should it take; how reliable does it have to be; and how flexible does it have to be?

Operability Criteria

We attacked the question of operability first. The number of operators we had was four; two on each shift, with an overlap, so all were often available at shot time. We wanted to reduce the number of operators required to a minimum and also wanted the control room operation to be simple enough to train new operators in a matter of 8-10 weeks, instead of 6 months to a year with the original system. We decided to design a system which would allow a single operator to fire a shot. That decision meant two

actions had to be taken: 1) the control system had to be automatic or semiautomatic; and 2) the control room had to be redesigned based on human factors. The automation design and the human factors design affected each other since the programs that needed an operator response had to be incorporated into the control room design. Thus, the control room design assumed the semiautomatic operating mode to be the normal operating mode.

Reliability Criteria

Reliability was an important consideration but not in the traditional sense. From the nuclear power industry, the most reliable system is one that operates continuously without failure. The computer would have an uninterruptable power supply, and controls would probably have redundant backups. Our application didn't need that level of reliability; we could tolerate short-term failures on an infrequent basis but not long-term failures that would prevent executing a shot. Therefore, the subsystem's controller programs were designed to protect the system, to shut down in situations they did not recognize, and to return control to a human operator, thus avoiding damage to major pieces of equipment. Tested spares for many components are kept on hand to facilitate rapid recovery from failures. The host computer was put under a 4-hour response service contract, and we kept spare PC boards critical to our application. The weak hardware lilnk is the subsystem controllers. Each has a processor board, an I/O board, and a memory (PROM) board that are identical, but each is completely customized for its application. The I/O board is also a custom board that is not supported by the original supplier, and there are no spares. This situation led to a proposal (discussed later) to replace the 8080 subsystem controllers with other hardware. We kept the reliability of the system high by not requiring the computer or all the subsystem controllers to be on-line for a shot. By retaining the manual control capability, an experienced operator could work around a "down" controller, though he would require assistance.

Flexibility Criteria

Flexibility was another main criterion. PBFA I not only is a fusion experimental driver but is also an experiment in itself. The driver experiment has been to refine existing operating techniques, try new ones, and find the best ways to operate a large accelerator. In this continuing experiment, operating parameters change. For example, the nine Marx pulser units (MPUs) that trigger the 36 Marx generators were individually, tested and characterized by their manufacturer. The recommended operating parameters were 80 KV charge and 80 psig gas switch pressure. We found that by increasing the charge and reducing the pressure, the MPUs as a system had 50% less spread. The original control software had not allowed for these kinds of changes. To implement a new control system with the same difficulty in incorporating changes would be foolish. The new system therefore has flexibility designed in hardware and software.

Hardware Flexibility

In the hardware, where we must use the 8080-based controllers, we have added a CAMAC [1] Crate to the timing-triggering system to allow us to program delays and trigger the accelerator from the host computer. While we were bringing the timing system interface on-line, we found a multitude of modules available for CAMAC. A brief literature survey showed us that we could add process control functions to the host computer through these modules. The first addition was the control of an experimenter's capacitor bank. An analogue input module, a digital input module, and a digital output module gave us sufficient capability to control the capacitor bank charging, voltage level, and safing. So, a proposal to gradually replace some or all of the 8080 controllers with

sample rate, the monitor and control programs now will be coordinated by the T&F program. The Report Generators and UPDATE program are not shown in Figure 4 but continue to be used. The T&F program will handle the operator interface, coordinate, schedule the corollary programs, and do error handling. The T&F program would have two modes, an interactive mode that was used mainly for testing, and a command file mode that consisted of sets of commands already translated by a Command Validator Program into the form that could be sent by the control program. These command files would be created by the operator before the shot and would have various functions, matching the various types of shots and shot preparation.
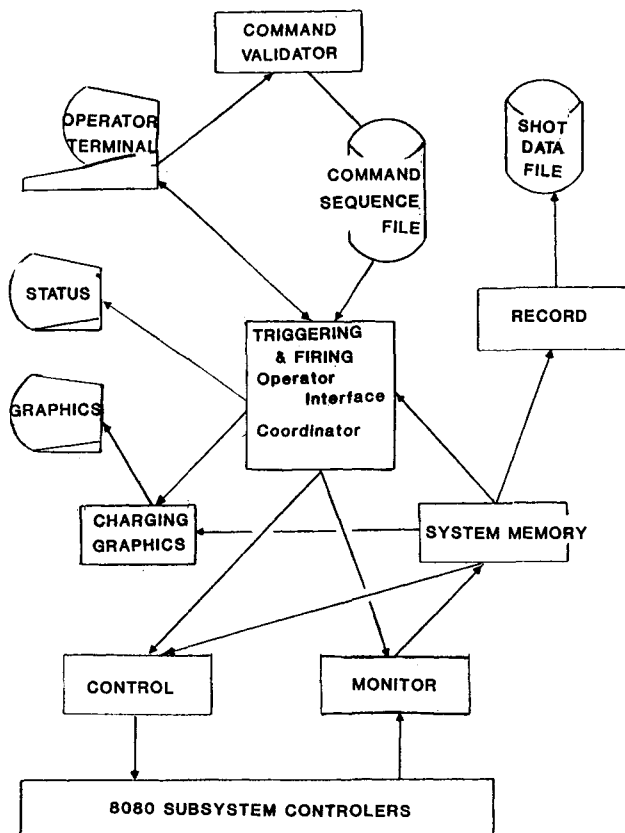

Figure 4. Automatic Software Configuration

Operation in the automatic mode would not exclude operator intervention. For instance, if during the execution of the "Full Shot" command file a situation occurred that required operator attention, an error message would be sent to the Error and Status terminal, the operator terminal would get a menu of possible actions, and the sequence would go into a HOLD, waiting on an operator command. The operator can then Continue from that point in the command file, Restart the command file, or ABORT; the last would start another command file to take the machine to a safe condition. The operator could also initiate a hold by pressing a preprogrammed key.

This design, though its purpose is to put the period from 10 minutes before to 5 minutes after the shot in automatic mode, is flexible enough to be expanded to a 24-hour facility monitor.

Summary

Moving from plan and design to implementation is always the most difficult part of a project. We have moved forward with the designed upgrades intermittently. The semiautomatic mode worked very well, with the exception that it was not flexible enough. A parameter or procedure change meant testing a new program and burning new PROMS. This made some changes difficult since testing some programs required firing the accelerator. Program priorities reduced our resources and has delayed implementation.

The PBFA I Control system is presently being operated in a semiautomatic mode, with work slowly continuing toward the completion of the designed automatic system.

Reference

[1] CAMAC – Computer Acquisition Measurement And Control, A High Level I/O System designed per IEEE Standards: 583, 683, 596, 595, and 758.

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